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## **CHAPTER 2.**

# **Components of Biocriteria**

**W**ater resource legislation is usually designed to protect the resource and to ensure its availability to present and future generations. Over the past two decades, legislative and regulatory programs have established goals such as "fishable and swimmable, antidegradation, no net loss, and zero discharge of pollutants." However, actions to meet those goals do not always accomplish the mandate of the Clean Water Act, which is to restore and maintain biological integrity. The purpose of this chapter is to provide managers with a basic conceptual understanding of the relationship between biological integrity and biocriteria and to describe more fully the biocriteria process.

### **Conceptual Framework and Theory**

Biological integrity was first explicitly included in water resource legislation in the Water Pollution Control Act Amendments of 1972 (Pub. L. 92-500); and the concept, which was retained in subsequent revisions of that act, is now an integral component of water resource programs at state and federal levels (U.S. Environ. Prot. Agency, 1990).

The goal of biological integrity, unlike fishable and swimmable goals, encompasses all factors affecting the ecosystem. Karr and Dudley (1981; following Frey [1975]) define biological integrity as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." That is, a site with high biological integrity will have had little or no influence from human society.

Edwards and Ryder (1990) recently used the phrase "harmonic community" in a similar context to describe the goal of restoring ecological health to the Laurentian Great Lakes. The sum of balanced, integrated, and adaptive chemical, physical, and biological data can be equated with ecological integrity (Karr and Dudley, 1981). Such healthy ecological systems are more likely to withstand disturbances imposed by natural environmental phenomena and the many disruptions induced by human society. These systems require minimal external support from management (Karr et al. 1986).

#### **Purpose:**

*To provide managers with a basic conceptual understanding of the relationship between biological integrity and biocriteria, and to describe more fully the biocriteria process.*

*It is important to distinguish between the attributes of natural systems that we intend to protect (assessment endpoints) and the attributes that we can measure (measurement endpoints). Success in protecting biological integrity depends on the development of measurement endpoints that are highly correlated with assessment endpoints.*

The adjective "pristine" is often invoked in such discussions; however, in the late 20th century, it is almost impossible to find an area that is completely untouched by human actions. Thus, the phrase "minimally impaired" is more appropriate than the word "pristine" for describing conditions expected at sites exhibiting high biological integrity.

Degradation of water resources comes from pollution, which is defined in the Clean Water Act of 1987 as "manmade or man-induced alteration of the chemical, physical, biological, or radiological integrity of water" (U.S. Gov. Print. Off. 1988). This comprehensive definition does not limit societal concern to chemical contamination. It includes any human action or result of human action that degrades water resources. Humans may degrade or pollute water resources by chemical contamination or by altering aquatic habitats; they may pollute by withdrawing water for irrigation, by overharvesting fish, or by introducing exotic species that alter the resident aquatic biota. The biota of streams, rivers, lakes, and estuaries, unlike other attributes of the water resource (e.g., water chemistry or flow characteristics), are sensitive to all forms of pollution. Thus, the development of biological criteria is essential to protect the integrity of water resources.

### ***Components of Biological Integrity***

While these definitions of integrity establish broad biological goals to supplement more narrowly defined chemical criteria, their use depends on the development of rigorous biological criteria. The challenge is to define biological integrity clearly, identify its components, and develop methods to evaluate a water resource and its surrounding environment based on these conditions.

Evaluating the elements or components of biological integrity will involve direct or indirect evaluations of biotic attributes. Indirect evaluations are appropriate if direct approaches are prohibitively expensive or in other ways difficult to implement. It is important to distinguish between assessment and measurement endpoints. Attributes of natural systems that we intend to protect, for example, the health of a fish population, are assessment endpoints; and attributes that we can measure, for example, age and size classes of the fish population, are measurement endpoints. Success in protecting biological integrity depends on the development of measurement endpoints that are highly correlated with assessment endpoints.

Important components of biotic integrity have been measured before. Toxicologists have long recognized the importance of individual health in evaluating the extent to which human actions have degraded a water resource, and ecologists have long used the kinds and relative abundances of species as indicators of condition. More recently, and in many ways less insightfully, theoretical measures of diversity have been used to assess species richness, that is, to determine if the number of species or relative abundances of species have been altered. Fish biologists, for example, use a variety of measures to assess the health of populations of targeted species, such as game fish. However, none of the attributes used in the past are comprehensive enough to cover all components of biological integrity.

In recent years, a broader conceptual foundation has been developed to convey the breadth of biotic integrity. The original Index of Biotic Integ-

rity (IBI) consisted of 12 metrics or attributes in three major groups: species richness and composition, trophic structure, fish abundance and condition. Another way of describing biotic integrity contrasts the elements of the biosphere with the processes but argues that both are essential to the protection of biological integrity (Table 2-1). The most obvious elements are the species of the biota, but additional critical elements include the gene pool among those species, the assemblages, and landscapes.

**Table 2-1.—Components of biological integrity.**

ELEMENTS	PROCESSES
Genetics	Mutation, recombination
Individual	Metabolism, growth, reproduction
Population/species	Age specific birth and death rates Evolution/speciation
Assemblage (community and ecosystem)	Interspecific interactions Energy flow
Landscape	Water cycle Nutrient cycles Population sources and sinks Migration and dispersal

Modified from Karr, 1990.

Processes (or functional relationships) span the hierarchy of biological organization from individuals (metabolism) to populations (reproduction, recruitment, dispersal, speciation) and communities or ecosystems (nutrient cycling, interspecific interactions, energy flow). For example, an important process in streams is an interaction of fish and mussels in which larval stages of the mussel (glochidia) attach to fish gills, presumably to enhance dispersal and to avoid predation.

Other approaches are available, but the important issue is not which classification is the best approach. Rather, efforts to assess biological integrity must be broadly based to cover as many components as possible.

The challenge in implementing biocriteria is to develop reliable and cost-effective ways to exploit the insight available through biological analyses. It is not necessary to sample the entire biota. Rather, carefully selected representative taxa should be sampled. The selection should combine as many attributes as possible with precision and sampling efficiency, but all elements and processes are not necessarily covered in standard biological sampling.

Recent efforts to develop such integrative approaches include Karr's IBI later expanded to apply to a wide geographic area (Ohio Environ. Prot. Agency, 1987; Lyons, 1992; Oberdorff and Hughes, 1992), and to taxa other than fish, for example, benthic invertebrate assemblages (Ohio Environ. Prot. Agency, 1987; Plafkin et al. 1989). The Nebraska Department of Environmental Control (Bazata, 1991) has proposed indices that combine fish and invertebrate metrics, and the Ohio Environ. Prot. Agency (1987) has calculated several indices separately (fish and invertebrates) but uses them in combination to determine use attainment status.

**E**fforts to assess biological integrity must be broadly based to cover as many components as possible.

*The choice of attributes to be assessed and measured is critical to the success of any biological monitoring and criteria program.*

*The best approach to assessing biological integrity seems to be an integrative one that combines assessment of the extent to which either the elements or the processes of biological integrity have been altered; that is, efforts to protect biotic integrity should include evaluation of a broad diversity of biological attributes.*

## **Assessing Biological Integrity**

A sound monitoring program designed to assess biological integrity should have several attributes. A firm conceptual foundation in ecological principles is essential to a multidimensional assessment that incorporates the several elements and processes of biotic integrity. The use of the concept of a reference condition, a condition against which a site is evaluated, is also important.

In addition, the general principles of sound project management or Total Quality Management (TQM), such as Quality Assurance and Quality Control, are as critical as the use of standard sampling protocols. *Quality assurance* (QA) includes quality control functions and involves a totally integrated program for ensuring the reliability of monitoring and measurement data; it is the process of reviewing and overseeing the planning, implementation, and completion of environmental data collection activities. Its goal is to assure that the data provided are of the quality needed and claimed.

*Quality control* (QC) refers to the routine application of procedures for obtaining prescribed standards of performance during the monitoring and measurements process; it focuses on the detailed technical activities needed to achieve data of the quality specified by the Data Quality Objectives (DQOs). Quality control is implemented at the laboratory or field level. Finally, biological monitoring must go beyond the collection and tabulation of high quality data to the creative analysis and synthesis of information about relevant biological attributes.

Numerous attributes of the biota have been used to assess the condition of water resources. Some are difficult and expensive to measure while others are not. Some provide reliable evaluations of biological conditions while others, perhaps because they are highly variable, are more difficult to interpret. Thus, the choice of attributes to be measured and assessed is critical to the success of any biological monitoring and criteria program.

Historically, most biological evaluations were designed to detect a narrow range of factors degrading water resources. For example, the biotic index (Chutter, 1972; Hilsenhoff, 1987) is designed to detect the influence of oxygen demanding wastes ("organic pollution") or sedimentation, as is the Saprobic Index developed early in this century (Kolkwitz and Mars-son, 1908).

With increased understanding of the complexity of biological systems and the complex influences of human society on those systems, more integrative approaches for assessing biological integrity have been developed. Some (Ulanowicz, 1990; Kay, 1990; Kay and Schneider, in press) advocate the use of thermodynamics, while others concentrate on richness or diversity (Wilhm and Dorris, 1968). The best approach seems to be an integrative assessment of the extent to which either the elements or the processes of biological integrity have been altered; that is, efforts to protect biotic integrity should include evaluation of a broad diversity of biological attributes.

Because the goal of biocriteria-bioassessment programs is to evaluate water resource systems stressed by or potentially destroyed by human action, the selection of the monitoring approach is critical. Indicators and monitoring design should be structured so that the same monitoring data

can serve a multitude of needs. This openness requires a reasonable level of sophistication for long-term status and trends monitoring. The more complicated the water resource problem, the larger the number of attributes that should be measured. Finally, programs to monitor the effects of human activity on the environment should have especially broad perspectives to ensure sensitivity to all forms of degradation.

### ***Complex Nature of Anthropogenic Impacts***

A number of human activities strain the integrity of water resource systems and the cumulative impacts of these actions create even greater complexity. Thus, it is useful, perhaps even necessary, to develop an organizational framework within which factors responsible for degradation in biotic integrity can be evaluated.

A major weakness of past approaches to protect water resources has been a narrow focus on the factors responsible for degradation. Specifically, past approaches focused on reducing the chemical contamination of the water on the assumption that clean water would produce high quality water resources. Overall, the determinants of the biological integrity of the water resource are complex, and the simplistic approach of making water cleaner, though important, is inadequate.

Biological monitoring and the use of biocriteria to assess biotic integrity provides a more comprehensive evaluation of the status of the resource. Such evaluations enhance our ability to identify the factors responsible for degradation and to treat the problem in the most cost-effective manner. Monitoring specific and ambient (background) conditions offers unique opportunities to detect, analyze, and plan the treatment of degraded resources.

Because human actions may impact a wider range of water resource attributes than water chemistry alone, a broader framework is necessary to identify and reverse the specific factors responsible for the degradation of biotic integrity. Degradation may begin in an area of the watershed or catchment that is external to the reference or test site simply because it is often the result of human actions that alter the vegetative cover of the land surface. These changes combined with the alteration of stream corridors degrade the quality of water delivered to the stream channels and attack the structure and dynamics of those channels and their adjacent riparian environments.

Human activities at the site affect five primary classes of variables — all of which may result in further degradation of water resources (Karr, 1991). These five internal variables should be placed in a larger context as illustrated in Figure 2-1:

1. **Water Quality:** Temperature, turbidity, dissolved oxygen, acidity, alkalinity, organic and inorganic chemicals, heavy metals, toxic substances.
2. **Habitat Structure:** Substrate type, water depth and current velocity, spatial and temporal complexity of physical habitat.
3. **Flow Regime:** Water volume, temporal distribution of flows.

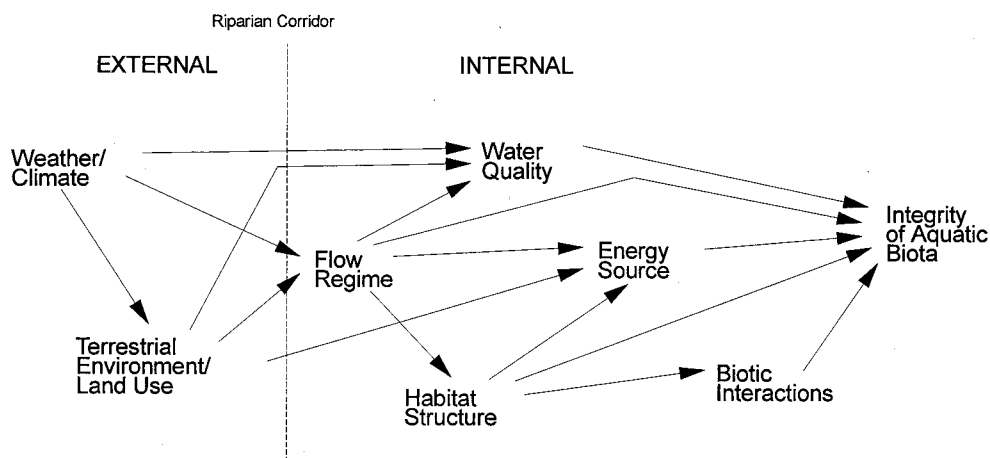


Figure 2-1.—Conceptual model showing the interrelationships of the primary variables relative to the integrity of aquatic biota. External refers to features outside the stream system; internal to in-stream features (Karr, 1991). Terrestrial environment includes factors such as geology, topography, soil, and vegetation.

4. **Energy Source:** Type, amount, and particle size of organic material entering stream; seasonal pattern of energy availability.

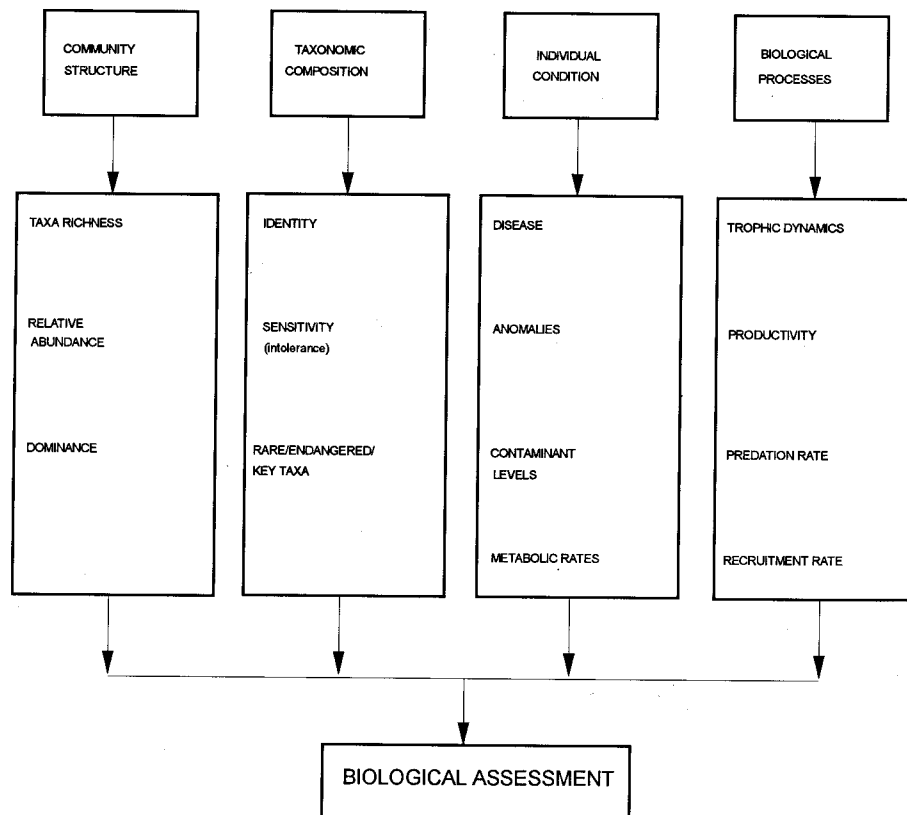
5. **Biotic Interactions:** Competition, predation, disease, parasitism, and mutualism.

From this conceptual framework, at least four components of the biota should be evaluated: structure, composition, individual conditions, and biological processes (Fig. 2-2). Sample attributes for each component include the following:

- **Community Structure:** Species richness, relative abundances, including the extent to which one or a few species dominates.
- **Taxonomic Composition:** Identity of the species that make up the biota.
- **Individual Condition:** Health status of individuals in selected species.
- **Biological Processes:** Rates of biological activities across the biological hierarchy (from genes to landscapes).

Comprehensive assessments of these attributes ensure that all the components of biotic integrity are protected. For each component, one or more attributes should be assessed.

Successful metrics represent the expression of the influence of human activities on the resident biota. For example, the presence of a few hardy species of fish in abundance may be a response to sewage in the waters. As human disturbance increases, total species richness, the number of intolerant species, and the number of trophic specialists usually decline, while the number of trophic generalists increases. *Generalists* are organisms that can use a broad range of habitat or food types. Exceptions exist: for example, when coldwater streams are warmed, species richness increases, although this process must be viewed as a degradation of the biotic integrity of a coldwater system.



**Figure 2-2.—Organizational structure of the attributes that should be incorporated into biological assessments.**

Use of biocriteria to evaluate and protect biotic integrity focuses directly on the condition of the resource. The development of biological monitoring is driven by the need for rigorous standardized evaluations of point and nonpoint source pollution and other circumstances in which up- and downstream evaluations may be inappropriate. In short, development of biocriteria is driven by the need for a comprehensive approach to the study and remediation of human effects on water quality.

## The Biocriteria Development Process

Biocriteria must be developed with a clear understanding of several important concepts. Foremost is the basic premise underlying biocriteria development: understanding the condition of the biota in a given waterbody provides a baseline for an integrative and sensitive measure of water quality. Biocriteria are operational narrative or numeric expressions that characterize and, if properly used, protect biological integrity.

Biocriteria can be used to protect biological integrity and to establish an aquatic life use classification. Following the definition of biocriteria, field surveys are conducted to determine whether particular sites meet the biocriteria or whether they have been affected by human activity. This determination is made by comparing the aquatic biota at potentially disturbed sites with minimally impaired reference conditions. Natural events

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*Once defined, biocriteria for a stream or river will describe the best attainable condition.*

not initiated by or exacerbated by human actions (e.g., fire, beavers) are not considered disturbances in this sense.

The basic premise, that biota provide a sensitive screening tool for measuring the condition of a water resource, depends on the assumption that the greater the anthropogenic impact in a watershed, the greater the impairment of the water resource. A corollary is that streams and rivers not subject to anthropogenic impact contain natural communities of aquatic organisms that reflect unimpaired conditions. These assumptions provide the scientific basis for formulating hypotheses about impairments — departures from the natural condition result from human disturbances.

Natural disturbances, such as floods or drought, may also affect the aquatic biota as part of normal ecological processes, and these responses vary among ecoregions and stream sizes. For example, relatively stable structure is characteristic of fish communities in the eastern United States but stable fish communities in the Great Plains streams may reflect human disturbance (Bramblett and Fausch, 1991). Molles and Dahm (1991) provide additional cautions on the need to consider natural events in interpreting data from biological systems. Thus, natural disturbances must be considered, but they are not considered as impairments because they are not the result of human activity.

Ideally, biocriteria are reflective of the natural biological integrity of the particular region under study, that is, of the region as it would be had it not become impaired. Depending on the refinement of the biosurvey method, the degree of impairment can often be established as part of the biocriteria development process. Once defined, biocriteria for a stream or river will describe the best attainable condition. The best attainable conditions represent expected conditions and are directly compared to the observed conditions. Each state needs to formulate appropriate definitive descriptors (i.e., biocriteria) for the aquatic organisms in its streams, and these descriptors or biocriteria should support the state's designated use classifications or other resource protection and management objectives.

Successful implementation of biocriteria requires a systematic program to collect and evaluate complex scientific information and translate that information into an effective planning tool to protect water resources. This effort must be systematic as well as conceptually and scientifically rigorous; it must also be logical and easily understood. The components of a program to implement biocriteria may be divided in a variety of ways.

The four primary steps to develop and implement biocriteria are introduced here and will be discussed in greater detail in later sections of this document. The four steps are

1. planning the biocriteria development process,
2. designating the reference condition for biosurvey sites,
3. performing the biosurveys to characterize reference condition, and
4. establishing biocriteria based on reference biosurvey results.

Each step must be considered in the context of regulatory policy, the scientific method, and the practical aspects of fieldwork involving biosurveys. Further, acceptable biocriteria for streams and rivers can be devel-

oped in various ways. Therefore, biocriteria development should be based on a set of flexible procedures derived from management, the regulatory process, or both. When properly implemented, the procedures lead to self-defined biocriteria that will protect the unique characteristics of streams and rivers. When not properly implemented, water resources continue to be degraded. Although the general concepts and procedures of biocriteria development can be adapted to any stream or river, the development of useful biocriteria requires individual planning for different waterbodies.

■ **Planning Biocriteria.** Planning includes the classification of surface water types and the definition of designated uses; however, the planning process necessarily extends beyond stream and river use classification. To be effective, planning must ensure that program objectives are clearly defined and that the scientific information generated to meet program objectives is appropriate for making environmental management decisions.

The planning phase assumes the interaction of environmental managers (staff involved in policy, budgeting, and resource management) and technical staff (those involved in data collection and interpretation) to ensure that the environmental data to be collected are acceptable and meet the state's needs. To facilitate interaction, a formal quality assurance and quality control plan that includes the formulation of data quality objectives should be included in the biocriteria development process. Complete data quality objectives describe the decisions to be made, the data required and why, the calculations in which the data will be used, and time and resource constraints. They are used to design data collection plans and to specify levels of uncertainty. Levels of uncertainty pertain to the confidence that decision makers can realistically have that collected data will actually support particular conclusions.

Finally, interagency cooperation (within and among states) should be a critical component of the planning process. Time spent on developing good relations with other groups improves biocriteria and their use.

■ **Designating Reference Condition.** Designating the reference condition for biosurvey sites is the second major activity in biocriteria development. This continuation of the planning process shifts attention to the specific data needed to define the biotic conditions that would be expected to occur in the study stream in the absence of human impact. Issues requiring consideration at this stage of the process include

- the database to be formed and evaluated (e.g., the taxonomic assemblages or other biological attributes to be used to describe biological condition);
- the habitat types to be included in the survey (e.g., runs, riffles, pools, and snags);
- the type of reference conditions needed for the program or study being formulated (e.g., regional, ecoregional, or site-specific);
- the geographical scale to which the biocriteria are applicable (e.g., specific river reach, watershed, ecoregion, or other parameters);
- the temporal scale for which biocriteria are being considered (e.g., seasonal, annual, or multiyear);

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**D**efinition of the reference condition is a critical step in the process.

- how habitat will be assessed to ensure comparability between the reference condition and the habitat at the biosurvey site before human impacts;
- parameters and methods of measurement; and
- how data from the biosurvey are to be evaluated.

Data management, analysis, and reporting requirements should also be determined before any fieldwork is begun. Specific information dealing with the designation of reference condition and biosurvey sites is provided in Chapter 3.

Because knowledge of biological communities and habitats surrounding the surface waters of the study region is essential to effective biological monitoring, definition of the reference condition is a critical step in the process. Careful designation of the reference condition can reduce the likelihood of problems and minimize the costs associated with fieldwork.

Knowledge of the reference condition may derive from historical data or from pilot studies of local or regional sites that are relatively undisturbed. Macroinvertebrate and fish assemblage data have often been routinely collected by state fish and wildlife agencies, water quality agencies, universities, and others responsible for stream management. Although these historical databases are often overlooked in environmental evaluations, they can be valuable sources of information. An estimation of biological integrity at a minimally impaired site may be accomplished by reviewing existing data and publications for specific streams and rivers. Fausch et al. (1984) developed fish species richness expectations for several midwestern streams based on historical data sets. Obviously, the usefulness of historical data for establishing reference condition is dependent on the original objective of the data collection effort, the collection methods, and the quality of the data. Even if historical data are inadequate for direct use in designating the reference condition, they may provide substantial insight about preexisting conditions at the test or study sites.

■ **Performing Biosurveys.** Performance of the actual biosurvey to characterize the reference condition entails several activities. Often, a presurvey (pilot study) is necessary to finalize the study plan and the actual logistics of the fieldwork. Upon completion of the study plan, technical staff must be fully briefed regarding the study's objectives, quality assurance and quality control operations, and methods of data collection and summarization. At this point, the actual biosurvey may be performed. Biosurveys may include routine local monitoring, sampling over wide geographic areas, or special case evaluations at one or a few sites.

■ **Establishing Biocriteria.** After the biosurveys have been completed or the historical data evaluated, the biological status of the reference condition is used to help define the biocriteria. Based on the results of the surveys, some refinement of aquatic life use designations may be needed for particular streams or rivers. After writing the biocriteria, they must undergo final review and approval by each state and the EPA.

Certain attributes should be considered when drafting formal biocriteria. Ideally, biocriteria should be readily understandable and scientifically

and legally defensible. Further, they should be protective of the most sensitive element of the biota included in the designated aquatic life use of the stream or river and yet express an attainable condition.

Thus, biocriteria should be used in decision making, not only for routine management procedures but also for guiding resource policy determinations. For those decisions to be robust, quality assurance programs must ensure long-term database management, including data entry, manipulation, and analysis.

Biocriteria provide an initial determination of impairment or attainment. Their use may also help to determine sources and causes of degradation when combined with survey information and knowledge of how organisms react to different stresses (e.g., sight-feeding fish decline when turbidity increases; tolerant species increase with nutrient enrichment; anomalies of 40 to 60 percent occur only in the presence of complex toxic effluents and impacts). These response signatures are vital to the successful use of biocriteria to attain water resource protection.

The endpoint of water resource protection using biocriteria is broader than clean water. The endpoint of biocriteria and water resource legislation is "to restore and maintain the physical, chemical, and biological integrity of the nation's waters."

## Suggested Readings

- Davies, S.P., L. Tsomides, D.L. Courtemanch, and F. Drummond. 1991. Biological Monitoring and Biocriteria Development. Prog. Sum. Maine Dep. Environ. Prot., Augusta, ME.
- Gallant, A.L. et al. 1989. Regionalization as a Tool for Managing Environmental Resources. EPA/600/3-89-060. U.S. Environ. Prot. Agency, Environ. Res. Lab., Corvallis, OR.
- Karr, J.R. 1991. Biological integrity: A long-neglected aspect of water resource management. Ecol. Appl. 1:66-84.
- North Carolina Department of Environmental Health and Natural Resources. 1990. Standard Operating Procedures, Biological Monitoring. Environ. Sci. Branch, Ecosystems Analysis Unit, Biol. Assess. Group, Div. Environ. Manage., Water Qual. Sec., Raleigh, N.C.
- Ohio Environmental Protection Agency. 1987. Biological Criteria for the Protection of Aquatic Life. In The Role of Biological Data in Water Quality Assessment. Vol. 1. Div. Water Qual. Monitor. Assess., Surface Water Sec., Columbus, OH.
- . 1990. The Use of Biocriteria in the Ohio EPA Surface Water Monitoring and Assessment Program. Columbus, OH.
- Plafkin, J.L. 1989. Water quality-based controls and ecosystem recovery. Pages 87-96 in J. Cairns Jr., ed. Rehabilitating Damaged Ecosystems. Vol. 2. CRC Press, Boca Raton, FL.
- U.S. Environmental Protection Agency. 1990. Biological Criteria: National Program Guidance for Surface Waters. EPA-440/5-90-004. Off. Water, Washington, DC.

**B**iocriteria should be readily understandable and scientifically and legally defensible. Further, they should be protective of the most sensitive designated aquatic life use of streams and rivers and yet express an attainable condition.

**T**he endpoint of biocriteria and water resource legislation is "to restore and maintain the physical, chemical, and biological integrity of the nation's waters."